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INTERACTIVE EFFECTS OF HEAT LOAD AND RESPIRATORY STRESS ON WORK PERFORMANCE OF MEN WEARING CB PROTECTIVE EQUIPMENT

Arthur T. Johnson, et al

Edgewood Arsenal
Aberdeen Proving Ground, Maryland

December 1973

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INTERACTIVE EFFECTS OF HEAT LOAD AND RESPIRATORY STRESS ON WORK PERFORMANCE OF MEN WEARING CB PROTECTIVE EQUIPMENT

by

Arthur T. Johnson
Howard M. Berlin

Directorate of Development and Engineering

December 1973

DEPARTMENT OF THE ARMY
Headquarters, Edgewood Arsenal
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Interaction between the effects of respiratory stress and thermal stress has been objectively identified. Analyses of data on distance run, percentage of inspiration at termination, and respiration rate at termination indicate the low value of resistance, 0.1 mm H_2O-min/liter, to be the point at which interaction occurs The heat load value causing interaction is somewhat equivocal. A model has been proposed which is consistent with our results and which defines the stress limitations for different rates of exercise. With the use of this model, the value of 0.1 mm H_2O-min/liter has been objectively defined as the minimum effectual protective mask airflow resistance. Evidence is presented for exhalation time as the index of the respiratory stress limitation.

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SUMMARY

Interaction between the effects of respiratory stress and thermal stress has been objectively identified. Analyses of data on distance run, percentage of inspiration at termination, and respiration rate at termination indicate the low value of resistance, 0.1 mm H_2O-min/liter, to be the point at which interaction occurs. The heat load value causing interaction is somewhat equivocal. A model has been proposed which is consistent with our results and which defines the stress limitations for different rates of exercise. With the use of this model, the value of 0.1 mm H_2O-min/liter has been objectively defined as the minimum effectual protective mask airflow resistance. Evidence is presented for exhalation time as the index of the respiratory stress limitation.

PREFACE

The work described in this report was authorized under Task 1W662710A09504, Respiratory Protection Investigations. The work was begun in June 1971 and completed in November 1972.

Volunteers in this test are enlisted US Army personnel. These tests are governed by the principles, policies, and rules for medical volunteers as established in AR 70-25 and the Declaration of Helsinki.

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Acknowledgment

The authors wish to thank the following personnel for their generous assistance in the completion of this work: Dr. Ed Cummings for his practical advice and help in planning; Mr. Roland Dorsey for his excellent shop work; Dr. Neal Nunnelly, Mr. James Alter, Mr. John Wallace, and Mr. C. S. Vogel for their aid in performing the tests; and Mrs. Cathleen Johnson for her help with data reduction.

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I. INTRODUCTION.

Numerous studies have been conducted in which attempts were made to expand knowledge of the ergonometric aspects of the stresses attributed to heat load[1-4] or respiration.[5-11] Yet, there are those who do not admit to the strict separation of heat stress effects from respiratory stress effects. They claim that interaction is observed which compounds the separate stresses due to heat load and respiratory resistance, and the mere presence of either type of stress sensitizes a person to the effects of the other.[12] It has been found, however, that reports of interaction in the literature are very rare. Not only is interaction unproven, but objective discussions of interaction have been avoided. Nevertheless, its proponents are vocally insistent on its presence. In light of this, the present study was initiated to objectively assess the magnitude of the interactive effects of heat and respiratory stresses.

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[1] Breckenridge, J. R., and Goldman, R. F. Solar Heat Load in Man. J. Appl. Physiol. *31*, 659-663 (1971).

[2] Craig, F. N., and Cummings, E. G. Dehydration and Muscular Work. J. Appl. Physiol. *21*, 670-674 (1966).

[3] Craig, F. N., Cummings, E. G., and Bales, P. D. CRDLR 3101. Contribution of the E33 Hood to Heat Stress on Men Wearing CBR Protective Clothing December 1961. UNCLASSIFIED Report.

[4] Givoni, G., and Goldman, R. F. Predicting Rectal Temperature Response to Work, Environment, and Clothing J Appl Physiol. *32*, 812-822 (1972).

[5] Craig, F. N., Blevins, W. V., and Cummings, E. G Exhausting Work Limited by External Resistance and Inhalation of Carbon Dioxide. J. Appl. Physiol. *29*, 847-851 (1970).

[6] Craig, F. N., and Cummings, E. G. Breathing in Brief Exercise J. Appl. Physiol *15*, 583-588 (1960).

[7] Craig, F. N., Froehlich, H. L., and Blevins, W. V. EATR 4230. Inspiratory Resistance as a Limiting Factor in Exhausting Work. October 1968. UNCLASSIFIED Report.

[8] Cummings, E. G, Blevins, W. V., Greenland, C. M, and Craig, F. N. CWLR 2254. The Effects of Protective Masks on the Soldier's Ability to Run a Half Mile. October 1958. UNCLASSIFIED Report.

[9] Muller, K. The Effects of the CBR Protective Mask on the Magnitude of Ventilatory or Gas-Metabolic Function While at Rest and Under Working Conditions. Doctoral Dissertation, Nuremberg University. Technical Translation FSTC-HT-23-952-70 Defense Documentation Center, Cameron Station, Alexandria, Virginia. Attn. TSR-1.

[10] Silverman, L, Lee, G., Yancey, A R., Amory, L., Barney, L. J., and Lee, R. C. Fundamental Factors in the Design of Protective Respiratory Equipment: A Study and an Evaluation of Inspiratory and Expiratory Resistances for Protective Respiratory Equipment. OSRD Report 5339. Contract OEMsr 306. 1 May 1945. UNCLASSIFIED Report.

[11] Silverman, L., Lee, R. C., Lee, G., Brouha, L., Whittenberger, J. L., Stiff, J. F., Byrne, J. E., Jr., and Smith, D. P. Fundamental Factors in the Design of Protective Respiratory Equipment: End Point Breathing Rate Studies. OSRD Report 4229 Contract OEMsr 306. 1 August 1944. UNCLASSIFIED Report.

[12] Goldberg, M. N., Raeke, J. W., Jones, R. E, and Santschi, W. R. Individual Respiratory Protection Against Chemical and Biological Agents. Report Number 3. p 78. Contract DA18-035-AMC-286(A) January 1966. UNCLASSIFIED Report

II. MATERIALS AND METHODS.

Nine normal test volunteers, representing a cross-section of Army enlisted personnel (table I), were instrumented so that rectal temperature, heart rate, and respiratory airflow through the M17 protective mask could be obtained. Rectal temperature was measured with a YSI 701 thermistor probe inserted 8 to 10 cm beyond the sphincter. Heart rate was transduced with Microcom AKG 103 differential diodes placed slightly lower on the thorax than the pectoral muscles in order not to interfere with equipment being carried. The electrodes were held in place by the application of tincture of benzoate and "Blenderm" surgical tape. Respiratory airflow was obtained from a pressure tap located in the place of the speech diaphragm in an M17 protective mask.

Table I. Subject Data

Subject	Age	Height	Weight	Smoker?	Physical condition	Hours of experience with M17 before testing
		cm	kg			
JEB	24	178	86	Yes	Fair to good	1
JAC	21	167	73	No	Very good	2
RTC	24	188	82	No	Very good	2
KEH	23	183	82	Yes	Poor	2
BAJ	22	175	67	Yes	Very good	½
RPJ	24	185	81	No	Excellent	1
CSM	22	183	73	No	Good	1-2
SRR	21	188	82	No	Very good	½
SS	22	185	84	Yes	Very good	1

A telemetry backpack and harness weighing 15 kg and containing a 3-watt FM transmitter, batteries, and processing electronics was carried by the men. A PACE P109D ±0.5 PSID carrier differential pressure transducer, a linearization network for the thermistor probe, and a heart rate amplifier were contained in the backpack. Heart rate information was not easily obtained because of radio frequency interference between the input signal and processing electronics Attenuation of the transmitted signal by 20 db was the best solution in obtaining heart rate without affecting other transmitted data. Reception, detection, discrimination, and recording were accomplished in a laboratory located 400 m from the test site. All signals were recorded in analog form by both a CEC 5-133 oscillograph and a Honeywell 5600 magnetic tape recorder. In addition, radio voice communication was constantly maintained between the field and the laboratory.

To prevent mask resistance differences from being obvious, and the consequential introduction of any extraneous psychological factors, two M17 masks were modified so that filter blanks occupied the area normally reserved for the charcoal filter elements. Changes in resistance were obtained by changing low-, medium-, or high-resistance inlet ports (figure 1). These were coded discretely for our recognition. The M6 hood was used with the M17 mask, but it was not strapped under the arms or drawn tightly around the head.

Heat load variations were obtained by the use of different types of clothing. From data published by Goldman,[13] light clothing was represented by unstarched fatigues with shirt sleeves rolled up, producing a comfort index (im/clo) of about 0.37; medium clothing was represented by the charcoal impregnated CB protective overgarment (pants and blouse, no gloves), having im/clo $\approx$ 0.24; heavy clothing was obtained by wearing a poncho over fatigues with sleeves down, having im/clo $\approx$ 0.11. Not all subjects wore undershirts, but they were consistent in their underclothing throughout the duration of the test. All subjects wore standard issue boots.

Two subjects were simultaneously tested during each session. The M17 mask was calibrated on each subject both before and after each test, since Cummings[14] and Johnson *et al.*[15] have shown that facial contour significantly alters mask pressure-flow relationships. Pressure-flow calibration was accomplished by drawing air through the mask outlet valve into a calibrated Fisher-Porter rotometer. Each masked subject held his breath as the flow through the mask was incremented from 55 to 250 ℓ/min.

Once the subject was in the field, receiver signal strength was checked, mask pressure null was obtained, and rectal temperature was calibrated at 36.6°C and at 39.5°C by a fixed resistor network in the telemetry backpack. Temperature calibration was periodically monitored and re-adjusted to account for drifting. The subjects walked six laps around a 200-m course at the rate of 2 min 40 sec/200 m. The walking phase allowed all physiological parameters to establish their trends during light exercise. A pressure null and temperature calibration were obtained on the second, fourth, and sixth lap to insure accurate readings in spite of decrease of transmitter battery voltage with time. Temperature accuracy remained at ±0.1°C.

During the first half of the fifth lap, a Douglas bag was attached to the mask outlet valve to sample the expired air for percentage of oxygen.

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[13]Goldman, R. F. Systematic Evaluation of Thermal Aspects of Air Crew Protective Systems, in Behavioral Problems in Aerospace Medicine, Conference Proceedings of the Advisory Group for Aerospace Research and Development (AGARD) Paris, France. October 1967

[14]Cummings, E. G. EATR 4179 Physiological Comparison of the M17, Silicone M17, and E17 Protective Masks in a Hot-Humid Environment. March 1968 UNCLASSIFIED Report.

[15]Johnson, A. T., Micelli, T. M., and Masaitis, C. EATR 4712. Flow Regimes in Protective Masks. March 1973 UNCLASSIFIED Report

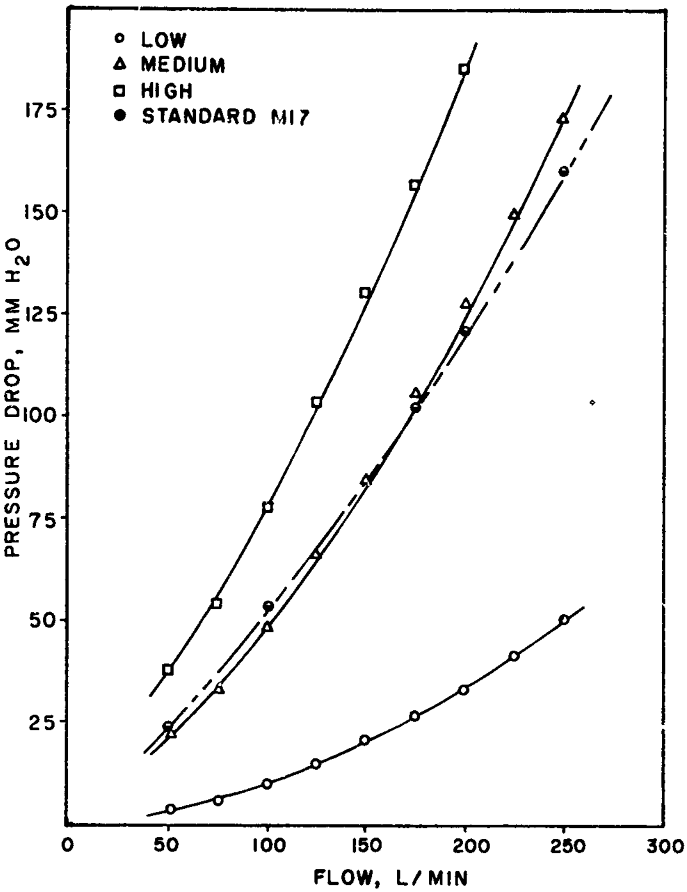

Figure 1. Flow-Pressure Curves for the Mask Resistances Used in the Test

After walking six laps, the subjects ran the same course at 70 sec/200 m until they reached a point consistent with the subjective feeling of "tiredness" they had experienced on previous tests in the program. Craig *et al.*[16] has termed this as their "voluntary end point." At the completion of each half lap, the subjects walked approximately 3 m in order to record useful heart rate information. Also, the subjects were offset by 100 m at the initiation of the run phase to minimize any competition with one another. Another Douglas bag was attached during the first half of the third running lap.

Wet bulb, dry bulb, and globe temperatures were recorded at the start and the completion of each test. A minimum dry bulb temperature of 23.9°C was established as a requirement before testing began for that day, although several times this minimum was not met (figure 2) and the test proceeded because of rescheduling difficulties. In these instances, the sky was clear and the radiant load was high.

Upon termination at the voluntary end-point, each subject was allowed to pull the M6 hood up to allow for faster relief from the heat, but his mask remained on until post-test pressure-flow calibration. The subjects were then asked for their reactions to that day's test and their answers were recorded for future evaluation.

Testing was scheduled so that each subject had adequate recovery time between tests. No one ran more than once on any particular day, and subjects were frequently scheduled at 1-½ days between tests.

III. RESULTS.

Statistically, this study was weak, with uncontrolled and unexplained variation at such a high level that significant effects are difficult to assess. Analyses of variances (ANOVA) are presented in the appendix.

Interaction between heat load and respiratory stress influencing the number of laps run is nonsignificant at any level of confidence, and resistance effects are insignificant at the 95% level. However, resistance effects are significant at the 90% level, which is perhaps better than accepting resistance effects as significant by a nonparametric procedure

Lap data are graphed as functions of resistance and heat load (figures 3 and 4). Linear relations are found in both instances. Because good subjective or objective bases could not be ascertained for differentiating between the heat loads caused by the poncho worn over fatigues versus charcoal overgarment, heat load data is plotted as a function of rate of rise of rectal temperature during the run rather than as a function of im/clo value.

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[16] Craig, F. N., Garren, H. W., Frankel, H., and Blevins, W. V. Heat Load and Voluntary Tolerance Time J. Appl. Physiol. 6, 634-644 (1954).

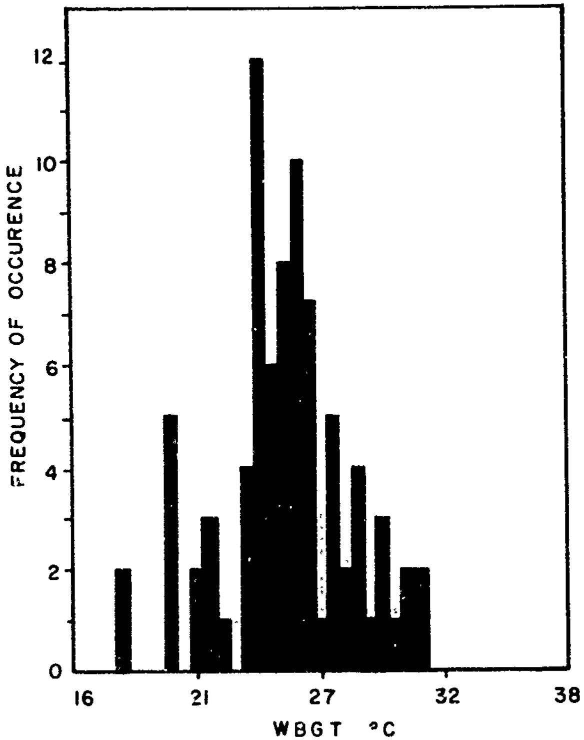

Figure 2. Frequency of Occurrence of the WBGT Index During Testing

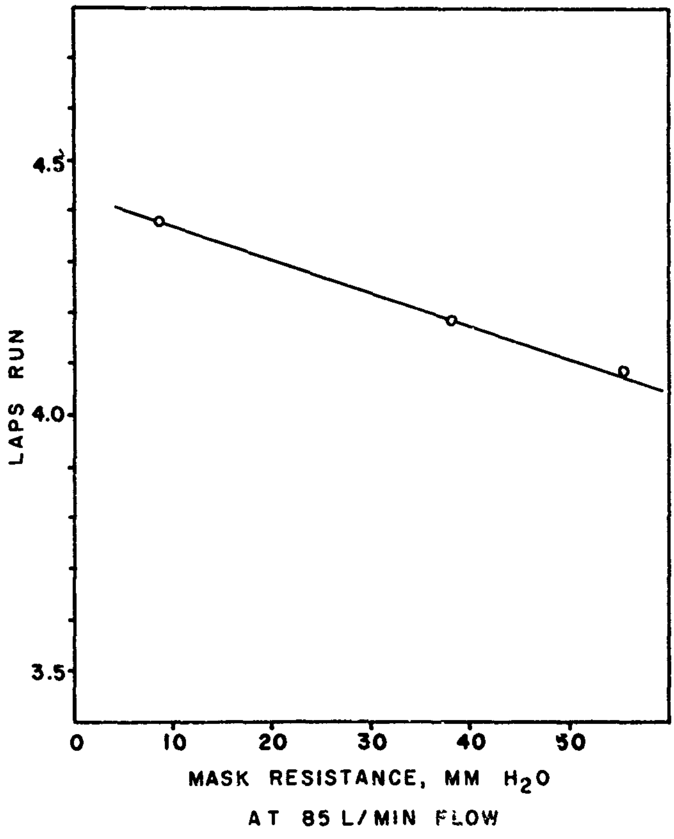

Figure 3. Distance Run as a Function of Mask Resistance

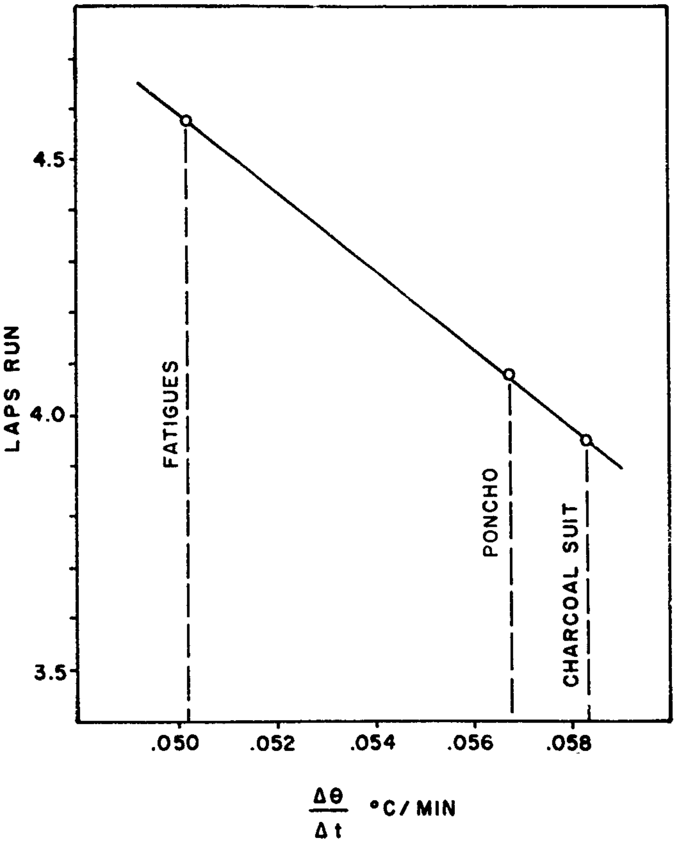

Figure 4. Distance Run as a Function of Heat Load

Metabolic energy expenditure was obtained from the percentage of oxygen in the exhaled air during the run, meteorological data, and subject data according to the method outlined by Consolozio *et al.*[17] Respiratory minute volumes during the run were extrapolated to their steady-state values since no recovery data was obtained. All calculations are normalized to a standard body weight of 68 kg and corrected to standard temperature and pressure conditions. Analyses of variances of energy expenditure (appendix) yielded no useful results.

Virtually no difference in respiratory rate appeared during the walk (table II), indicating that neither heat load nor mask resistance influenced that quantity. The analysis of variance suggests only a subject-to-subject difference. Contrarily, the percentage of the respiratory cycle devoted to inspiration appears to be sensitive to all but heat load effects.

Table II. Average Responses to Treatments

Constant treatment at all levels	Variable treatment-level	Average responses: Total work kg-m X 10^3	Number of laps	Response rate bpm (walk)	% Inspiration before run	% Inspiration @ termination
	Mask resistance					
At all levels	Low	40.34	4.39	24.5	47.96	52.22
Of heat load	Medium	39.78	4.19	22.9	48.85	55.11
	High	37.74	4.07	23.5	49.70	57.11
	Heat load*					
At all levels	0.050	42.69	4.59	23.9	47.96	55.11
Of mask resistance	0.057	38.69	4.13	23.4	49.59	55.28
	0.058	36.47	3.93	23.8	48.96	54.05

*Levels of heat load as determined from rate of rise of rectal temperature, °C/min.

IV. DISCUSSION.

A large error sum of squares in the ANOVA can obscure all but the most drastic of treatment effects. Such was the case in this study, but alternative methods frequently used by engineers proved able to extract useful results.

[17] Consolazio, C. F., Johnson, R. E., and Pecoria, L. J. Physiological Measurements of Metabolic Functions in Man. p 9. McGraw-Hill, New York, New York. 1963.

The effect of mask resistance on work performance is statistically insignificant at the 95% confidence level for distance run and total work. However, a definite linear relationship between mask resistance and distance run is demonstrated in figure 3. Interestingly enough, no more than a 10% advantage can be obtained for a 600% decrease in mask resistance for the conditions of this test. Similar observations encountered previously[8,18] may lead one to conclude that work performance is not sensitive to respiratory resistance changes in the range 0.1 to 1.0 mm H_2O-min/liter

Distance run was also a linear function of heat stress when expressed in terms of the rate of rise of rectal temperature. Considering the nominal im/clo index of each uniform resulted in a decrease, followed by an increase in distance run with apparent heat load. No attempt was made to correct the im/clo values for wind or body movements.[4] Nonstandard methods of wearing the clothing (for example, rolling the poncho up at the shoulders) was sometimes necessary to accommodate our telemetry gear and also could have contributed to the apparent discrepancy.

Analysis of variance of lap data indicates no significant interaction between heat and respiratory stresses. However, given the relatively large error mean sum of squares, it is highly likely that interaction, at most a secondary factor, would not appear to be a significant effect. Applying a procedure similar to that for analysis of direct clothing and resistance effects, the interaction may be seen graphically.

Figures 5 and 6 are graphs of response against levels of a single treatment with constant levels of the remaining treatment forming a family of curves. Interaction may be seen on graphs of this type when the curves are nonparallel.[4,19] In each family of curves, one line is not parallel to the other two. Interaction apparently occurs for a heat load of 0.057°C/min and resistance of 0.106 mm H_2O-min/liter. It must be emphasized that interaction does not appear to be a general effect, but is localized to a particular combination of heat load and respiratory resistance.

A probable mechanism for the occurrence of interaction between respiratory stress and heat load is thermally induced hyperventilation. This hypothesis is not entirely supported by the statistical analyses of respiratory data (appendix). Interaction appears to be most likely in the ANOVA of percentage inspiration at termination. In figure 7 is shown the strong influence of resistance and relatively indifferent effect of heat load on percent inspiration. Figures 8 and 9 display the manner in which percent inspiration varies with levels of resistance and heat load. Clear interaction can be seen for the low value of resistance. The data presented in figure 9, however, is much more confused, precluding independent definition of the area of interaction for levels of heat load.

A somewhat different set of results is obtained from the analysis of respiration rate data at termination. The ANOVA (appendix) indicates no significant heat load or interactive effects. A large resistance and subject effect is illustrated. Some training effect is also possible. Figure 10

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[18] Van Huss, W. D., and Heusner, W. W. The Respiratory Burden of the Field Protective Mask. Final Report. CRDL Task 1C622401A09701. 14 September 1965. UNCLASSIFIED Report.

[19] Federer, W. T. Experimental Design. pp 168-169. Macmillan Company, New York, New York. 1955

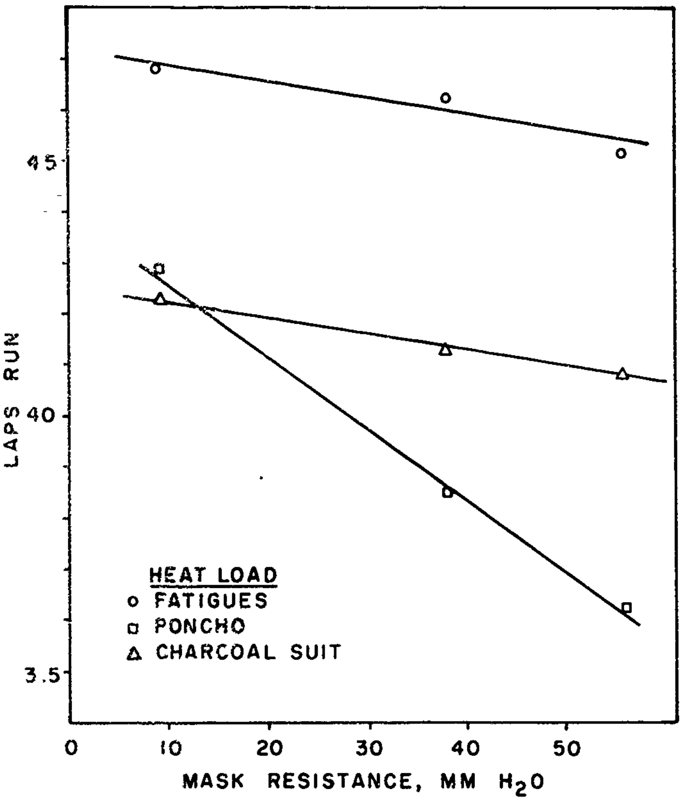

Figure 5. Distance Run as a Function of Mask Resistance for Three Levels of Heat Load

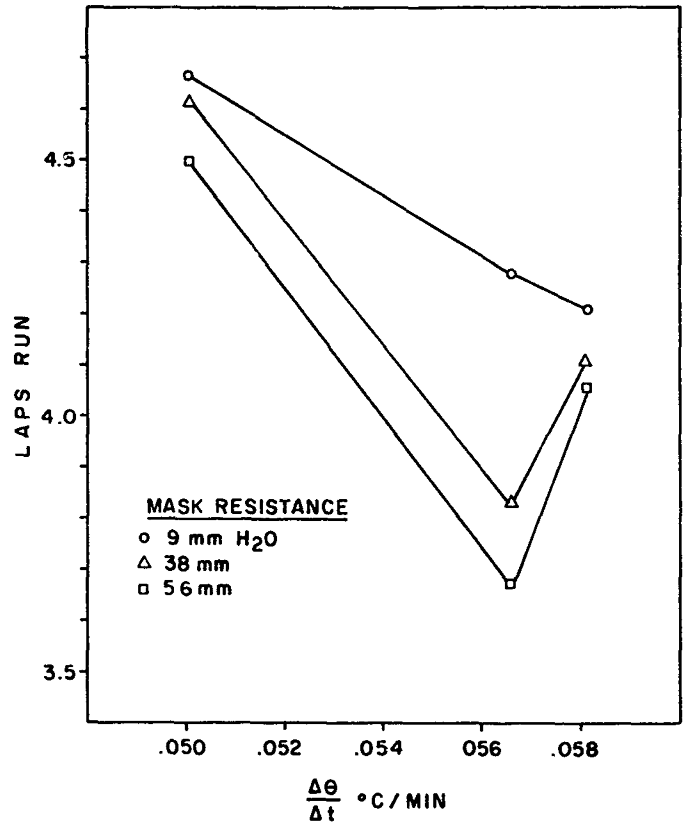

Figure 6. Distance Run as a Function of Heat Load for Three Levels of Mask Resistance

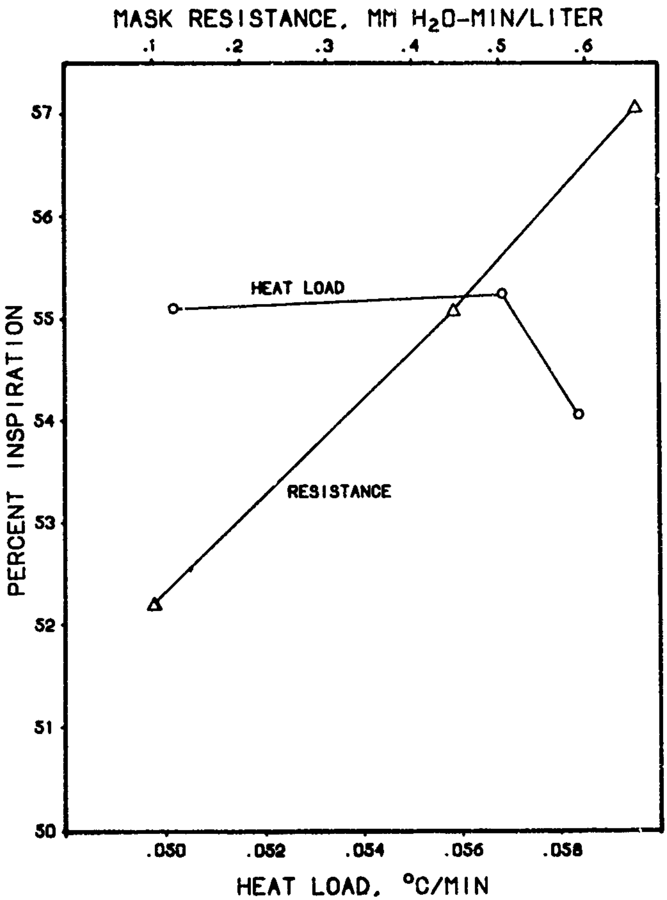

Figure 7. Percentage Inspiration at Termination Dependence on Mask Resistance and Heat Load

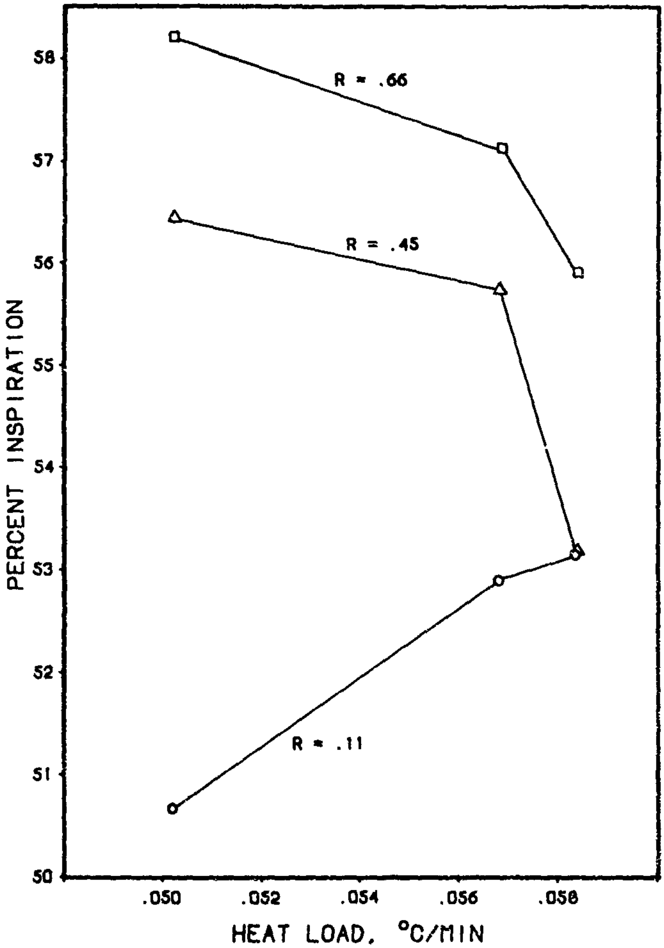

Figure 8. Percentage Inspiration at Termination as a Function of Heat Load for Three Levels of Mask Resistance

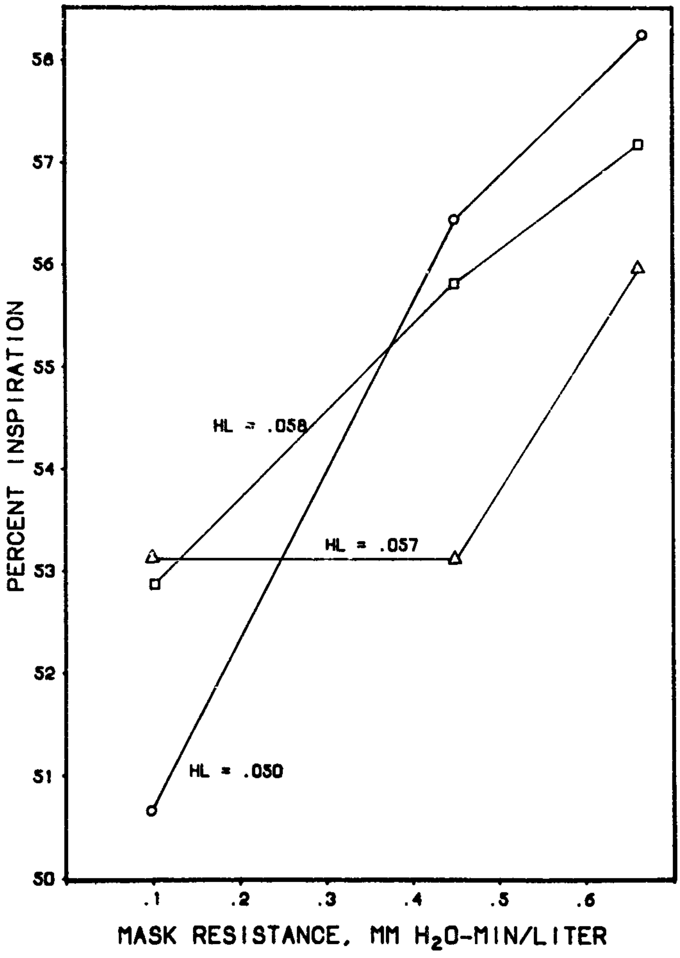

Figure 9. Percentage Inspiration at Termination as a Function of Mask Resistance for Three Levels of Heat Load

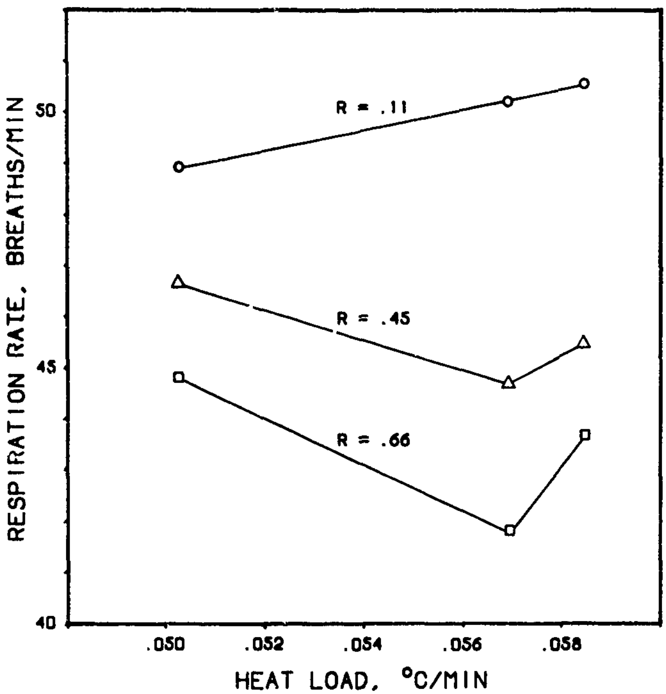

Figure 10. Respiration Rate at Termination as a Function of Heat Load for Three Levels of Mask Resistance

depicts the variation of respiration rate at termination as a function of heat load for three levels of mask resistance. Again, an interaction is discovered for the low value of mask resistance. In figure 11, the data is plotted as a function of mask resistance for three levels of heat load. Interaction can be inferred for the low value of heat load.

All graphs presented so far mutually confirm the low value of resistance as the point of interaction. The level of heat load causing interaction is questionable. Several possibilities present themselves: first, interaction occurs over all levels of heat load; or secondly, the two highest values of heat load are too close together to be differentiated with the methods used in this report. For the second case, heat load levels causing interaction cannot be identified unless one resorts to other methods.

It is appropriate here to propose a model which can delineate the stress limitation regimes for men performing physical tasks. With reference to figure 12, the stress limitation due to physical work is depicted as having a generally hyperbolic shape. It is known that at very high levels of work, the performance time is very short, and the major limitation appears to be circulatory (e.g., heart rate increases rapidly to maximal values). For work which is not quite as severe as that which causes circulatory stress limitations, the major cause of stress limitation is respiratory. As the level of work decreases, the major systemic stress limitation becomes, in turn, heat, dehydration, and starvation. Thus, the physical performance stress tolerance is composed of components describing individual circulatory, respiratory, heat, etc., stress tolerances. Time constants associated with each particular stress offset the curves from one another. The working individual is restricted by the type of stress imposing the minimum tolerance limitation at his particular exercise level.[20]

If interaction between two types of stresses were to occur, this model would predict its occurrence at the juncture of two stress domains. Interaction between respiratory and heat stresses should occur near the point of minimum respiratory stress limitation and maximum heat stress limitation. A glance at figures 5 and 6 reassures us that this is, in fact, the point where interaction has been discovered. The resistance level of 0.11 mm H_2O-min/liter has been described as subjectively unnoticeable,[16] which suggests the slightness of the respiratory resistance. Contrarily, the 0.06°C/min heat stress level is somewhat higher than the maximum heat stress of approximately 0.04°C/min reached by subjects in previously reported field tests.[21] Thus, the minimum expected respiratory stress level and the maximum expected heat stress level have been located

In previous studies[7-9,11,18] it had been somewhat unclear as to the maximum allowable respiratory resistance for an unstressful protective mask. The results presented here indicate objectively that the proper mask resistance should be in the neighborhood of 0.1 mm H_2O-min/liter.

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[20] Åstrand, I., Åstrand, P., Christensen, E. H., and Hedman, R. Intermittent Muscular Work. Acta physiol scand. *48*, 448-453 (1960).

[21] Yarger, W. E., Schwartz, P. L., and Goldman, R. F. Naval Medical Field Research Laboratory Interim Report M4305.06-3004B.1. An Assessment of CBR Protective Uniforms During an Amphibious Assault in a Tropical Environment Heat Stress Study 69-10. November 1969. UNCLASSIFIED Report

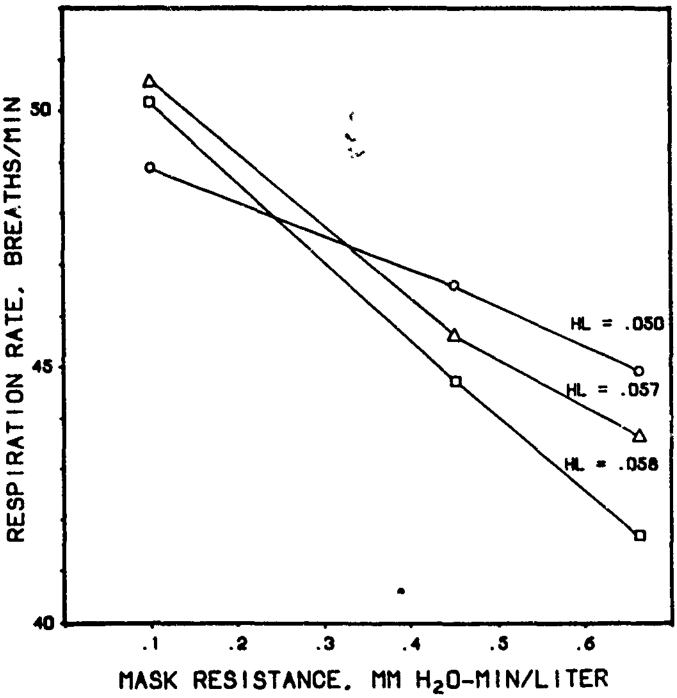

Figure 11. Respiration Rate at Termination as a Function of Mask Resistance for Three Levels of Heat Load

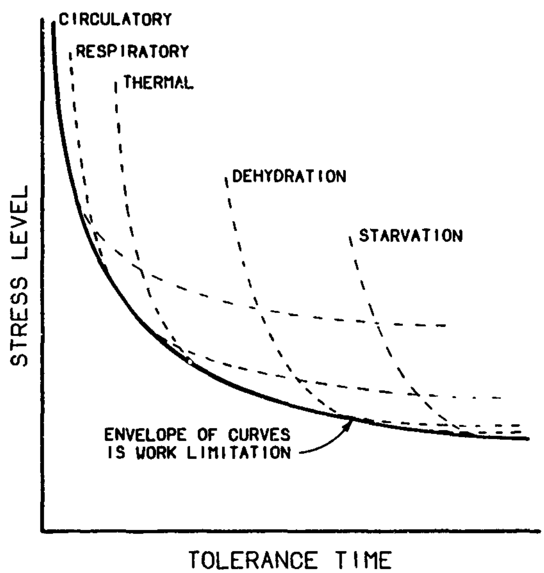

Figure 12. Model of the Exercise Tolerance Time as a Function of Stress Level

One difficulty in discussing the respiratory stress limitation is that very little is known concerning the restriction on respiratory stress. Heat casualties occur when rectal, or sometimes intracranial, temperature reaches approximately 40°C.[21] No similar limitation has been characterized for respiratory stress casualties. We noticed that the one subject who removed his mask because of respiratory stress had the highest percentage of inspiration with respect to the full respiratory cycle. It also appears as if this percentage increases with testing time and with inspiratory resistance. This agrees with the work of Johnson *et al.*[15] who showed theoretically that the inspiratory phase of respiration should increase as resistance is increased, and with the work of Silverman *et al.*[10] who demonstrated the same experimentally.

Craig *et al.*[5,18] indicate that perhaps the limitation lies not with inspiration, but instead, with expiration. In characterizing the voluntary tolerance time of men working at fairly high rates (necessary for a respiratory end-point as predicted by the model presented previously), they found a relatively constant expiratory time for each individual independent of oxygen debt, respiratory resistance, or pCO_2 level. Subjecting our data to a similar analysis produced comparable results (table III). For most subjects, the exhalation time at the voluntary end-point for all treatment levels was a constant with a standard deviation of roughly 10% of the mean. Those subjects with greater standard deviations may have lacked sufficient motivation to continue to the same end-point each time.

Table III. Exhalation Times for Test Subjects

Subject	Average time	Standard deviation	Variance
	sec	sec	sec
JEB	0.766	0.177	0.0314
JAC	0.398	0.037	0.00137
RTC	0.861	0.205	0.0422
KEH	0.530	0.0649	0.00421
BAJ	0.645	0.129	0.0166
RPJ	0.787	0.139	0.0192
CSM	0.741	0.0831	0.00691
SRR	0.535	0.0526	0.00277
SS	0.579	0.0550	0.00302

It is reasonable to suspect a minimum exhalation time limitation. As described by Hildebrandt and Young,[22] the rate of expiration is limited by the transbronchial pressure which tends to compress the lower air passages. This phenomenon is much more acute in patients with emphysema,[22,23] but it is present to a lesser extent in healthy subjects.

It was suspected from ideas presented in Milsum[24] that as respiratory resistance was added to the mask the average respiratory rate would decrease. This is because the respiratory system appears to adjust to the minimum work condition by varying respiratory rate and tidal volume to satisfy the minute volume requirement. Data in table II shows no significant change with resistance. The reason for this is open to speculation. Perhaps this is also proof of the insignificance of these levels of resistance. Muller[9] indicates an increase in internal resistance when a protective mask is added. The level change of external resistance may be small in comparison to this internal change.

The results of this study have added objective confirmation of the effects which heretofore have only been subjectively determined. The model proposed in figure 12 can be of great help in delineating areas of future work.

V. CONCLUSIONS.

The following conclusions have been reached:

1. A model has been proposed to explain the various limitations which are manifested when exercising at different rates.

2. Interaction between respiratory and thermal stresses has been identified. The interaction occurs in the vicinity predicted by the model.

3. Further evidence has been given to pinpoint a minimal exhalation time as the respiratory stress limitation.

4. The maximum mask resistance of 0.1 mm H_2O-min/liter has been found, above which a respiratory stress limitation may be reached.

VI. RECOMMENDATIONS

Further work is recommended because of the large number of unexplained errors incurred in this study. Work should be directed toward substantiating the results of this test.

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[24] Milsum, J. H. Biological Control Systems Analysis. pp 409-412. McGraw-Hill, New York, New York. 1966.

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APPENDIX

ANALYSES OF VARIANCE OF TEST DATA

The assumed model for the test data is:

$$X_{ijk\ell} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \beta_k + \beta_\ell + \epsilon_{ijk\ell}$$

$X_{ijk\ell}$ = individual result

where

μ = mean (fixed)

α_i = fixed resistance effect

β_j = random heat load effect (random because weather is uncontrolled)

$(\alpha\beta)_{ij}$ = random interactive effect

β_k = random subject effect

β_ℓ = time effect, assumed random

$\epsilon_{ijk\ell}$ = random error

The ANOVA table for the Latin Square with superimposed factorial treatment applications is:

Source	DF	Sums of Squares (SS)	Mean Square (MS)	F Ratio
Total	81	$\sum_{ijk\ell}(X^2_{ijk\ell})$		
Mean	1	$\frac{\sum_{ijk\ell}(X_{ijk\ell})^2 - C}{81}$		
Time	8	$\frac{\sum_{\ell}(\sum_{k} X_{ijk\ell})^2 - C}{9}$	Time SS/8	Time MS/Err MS
Subjects	8	$\frac{\sum_{k}(\sum_{\ell} X_{ijk\ell})^2 - C}{9}$	Subj SS/8	Subj MS/Err MS
Treatments	8	$\frac{\sum_{ij}(\sum_{k\ell} X_{ijk\ell})^2 - C}{9}$	Trt SS/8	Trt MS/Err MS
Resistance	2	$\frac{\sum_{i}(\sum_{jk\ell} X_{ijk\ell})^2 - C}{9}$	Res SS/2	Res MS/Int MS
Heat Load	2	$\frac{\sum_{j}(\sum_{ik\ell} X_{ijk\ell})^2 - C}{9}$	HL SS/2	HL MS/Err MS
Interaction	4	Trt SS - Res SS - HL SS	Int SS/4	Int MS/Err MS
Error	56	Tot SS - C - Time SS - Subj SS - Trt SS - Err SS/56		

When necessary, an unbiased estimate of missing data was calculated according to the method presented in Steel and Torre.[25]

1. Number of Laps Run.

Source	DF	Sums of Squares	Mean Square	F Ratio	Significant Level
Total	81	1634.2500			
Mean	8	1439.7808			
Subject	8	128.9136	16.1142	21.8	.00
Time	8	15.8025	1.9753	2.7	01
Treatment	8	8.3580	1.0448	1.4	.21
Resistance	2	1.3766	.6883	4.0	.11
Heat Load	2	6.3025	3.1512	4 3	.02
Interaction	4	6790	.1698	.2	.92
Error	56	41.3950	.7392		

[25] Steel, R.G.D., and Torre, J. H. Principles and Procedures of Statistics. pp 198, 145-152,210,222. McGraw-Hill, New York, New York. 1960.

2. Total Work for Standard Man.

Source	DF		Sums of Squares	Mean Square	F Ratio	Significant Level
Total	81		812948.59			
Mean	1		685997.84			
Subjects	8		77036.109	9629.5136	13.9	.00
Time	8		9141.2187	1142.6523	1.6	.13
Treatments	8		4041.3516	505.1690	0.7	.67
Resistance		2	555.6875	277.8438	2.0	.25
Heat Load		2	2938.1172	1469.0586	2.1	.13
Interaction		4	547.5469	136.8867	0.2	.94
Error	53		36732.078	693.0581		

3. Average Respiratory Rate During Walk.

Source	DF		Sums of Squares	Mean Square	F Ratio	Significant Level
Total	81		49437.463			
Mean	1		45382.253			
Subjects	8		3520.8359	440.1045	57.7	.00
Time	8		36.0903	4.5113	0.6	.78
Treatments	8		78.5493	9.8187	1.3	.27
Resistance		2	35.9106	17.9553	1.8	.27
Heat Load		2	3.1382	1.5691	0.2	.81
Interaction		4	39.5005	9.8751	1.3	.28
Error	55		419.7344	7.6315		

4. Percent Inspiration Before Run.

Source	DF		Sums of Squares	Mean Square	F Ratio	Significant Level
Total	81		194982.00			
Mean	1		193209 08			
Subjects	8		391.3613	48.9202	2.7	.01
Time	8		166.0273	20 7534	1.2	.35
Treatments	8		202.4727	25.3091	1.4	.22
Resistance		2	40.9180	20.4590	7	.57
Heat Load		2	36.4727	18 2363	1 0	.37
Interaction		4	125 0820	31.2705	1.7	.16
Error	56		1013.0566	18 0903		

5. Percent Inspiration After Run.

Source	DF		Sums of Squares	Mean Square	F Ratio	Significant Level
Total	81		244980 20			
Mean	1		243371.19			
Subjects	8		439.2773	54.9097	5.2	.00
Time	8		183.0508	22 8814	2.2	.05
Treatments	8		438 5859	54 8232	5.2	.00
Resistance		2	326 2090	163.1045	7.4	.05
Heat Load		2	23 8633	11.9316	1.1	.33
Interaction		4	88.5137	22.1284	2 1	09
Error	52		548.0957	10.5403		

6. Respiration Rate at Termination.

Source	DF	Sums of Squares	Mean Square	F Ratio	Significant Level
Total	81	187136.24			
Mean	1	176258.15			
Subjects	8	8295.3027	1036.913	32.0	.00
Time	8	359.3320	44.9165	1.4	.22
Treatments	8	506.8301	63.3538	2.0	.07
Resistance	2	462.1797	231.0898	22.6	.01
Heat Load	2	3.7363	1.8682	0.1	.94
Interaction	4	40.9141	10.2285	0.3	.87
Error	53	1716.6230	32.3891		